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The objectives of the effort were to improve our understanding of the dynamics of Langmuir circulation, to examine its role in controlling the vertical fluxes of heat and momentum which determine the mean vertical structure of the upper ocean, and to make progress toward incorporating the effect of Langmuir circulation in models predicting how the ocean responds to atmospheric forcing.

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The Effect of Langmuir Circulation on the Surface Boundary Layer

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The objectives of the effort were to improve our understanding of the dynamics of Langmuir circulation, to examine its role in controlling the vertical fluxes of heat and momentum which determine the mean vertical structure of the upper ocean, and to make progress toward incorporating the effect of Langmuir circulation in models predicting how the ocean responds to atmospheric forcing.

In 1990 we participated in the cooperative Surface Wave Processes Program (SWAPP). High vertical and temporal resolution measurements of velocity and temperature were made from the Research Platform FLIP. Surface wave and meteorological measurements were made at the same time. Collaborators (Smith, Pinkel, Farmer, Crawford) made acoustic Doppler current measurements, imaged bubble clouds, and collected profiles of microstructure near the surface. These data provided the information about the surface forcing (air-sea fluxes and surface waves), the Langmuir circulation, and the mixed layer structure needed to address the objectives. Following the field work we have organized meetings of the SWAPP participants to facilitate collaborative analyses, have exchanged data, and carried out analysis and publication.

The work has resulted in:

- the development of an objective measure of Langmuir circulation strength from the SWAPP observations.
- demonstration that Langmuir circulation effects the mean vertical structure of velocity in the surface boundary layer.
- demonstration that the observed time series of Langmuir circulation strength covaries with the Craik-Leibovich instability parameter.
- unique documentation of the sub-inertial variability of the vertical structure of the oceanic boundary layer.

A time series of the strength of the Langmuir circulation was produced for the duration of SWAPP. The observed strength of the circulation was found to be closely related to the magnitude of the instability parameter derived from the Craik-Leibovich theory. This result supports wave-current interaction theories of Langmuir circulation by showing that both wind stress and Stokes drift must be included in order to parameterize the variability of circulation strength. Thus, it was possible for the first time to relate variations in the forcing (in terms of the mean vertical shear and the surface wave Stokes drift) and in the vertical structure of the upper ocean to the strength of Langmuir circulation observed in the open ocean.

The mean vertical structure of the surface boundary layer was found to be not entirely consistent with present models and to have more shear at sub-inertial frequencies than anticipated from the Price-Weller-Pinkel (PWP) mixed layer model. At the inertial frequency, the vertical structure is closer to slab-like, with shear concentrated at the mixed layer base. The low-frequency shear was surface-intensified, coherent with the wind, and strikingly similar to that seen in numerical simulations of Langmuir circulation. Despite the complexity of the shear profile, the vertically integrated velocity agreed well with the

predicted Ekman transport. Because the surface-forced flow was dominated by near-inertial oscillations with shear concentrated at the mixed layer base, shear-driven mixing and mixed layer deepening was not apparently influenced by the low frequency shear. More often than not, PWP did well at predicting mixed layer depth and the vertical structure of temperature.

However, the presence of Langmuir cells did noticeably impact the evolution of the vertical structure during periods (tens of hours) immediately following strong wind events, when local winds were low but waves persisted. During these periods the PWP model predicted restratification in response to the combination of low wind and solar heating. However, the observations show that Langmuir cells persisted after the end of the wind forcing, redistributed the heat from the penetrating shortwave radiation, and kept the surface layer mixed. In addition to these periods following wind events and more generally, it was found that the variance of the high-frequency shear within the mixed layer was related to Langmuir circulation strength (Gnanadesikan et al., submitted). Thus, even when a deep mixed layer was correctly predicted by the PWP model during strong wind and waves, the slab-like structure of the predicted horizontal velocity field was in sharp contrast with the observed strong high frequency variability in near-surface shear.

The implication of these results is that although the bulk properties of the surface boundary layer can be reproduced with some success from existing models, the vertical distribution of heat and momentum within the boundary layer cannot be. The principal physical mechanism which remains unaccounted for in models is Langmuir circulation (Leibovich, 1983). Langmuir circulation arises from an instability of mean-flow shear in the presence of a surface wave Stokes drift. The results from SWAPP show that predictions of SST and near-surface vertical structure can be improved by incorporating into the models wave forcing and a proxy for mixing by Langmuir circulation.

These findings and the measurements of Langmuir circulation made from FLIP in MILDEX and more recently in SWAPP have had significant impact, causing renewed interest in modeling the impact of large eddies within the mixed layer on ocean physics, biology, and chemistry and in explicit consideration of surface wave forcing of the upper ocean. The basic research effort led the more applied modeling effort and to participation in shallow water acoustic reverberation experiments funded by the ONR ocean acoustics program.

Publications resulting from support under this grant:

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